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Environmental assessment of a pork-production system in North-East of Spain focusing on life-cycle swine nutrition

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ABSTRACT

Given the importance of pig-meat production in Spain, the present work (based on cumulative energy demand, global warming potential, ReCiPe method and different functional units) presents a life cycle assessment of an intensive pork-production system (growing-finishing pigs from 25 to 105 kg body weight) in North-East of Spain. Emphasis is given on animal feeding (which is separated into 3 phases) while the impact of drinking-water consumption, straw usage and transportation (for feed and straw) are also taken into account for certain scenarios. The results demonstrate that there is a cumulative energy demand of 5.6 MJ_{prim} per kg of animal feed and 14.5-35.6 MJ_{prim} per kg of meat (live or carcass weight). Moreover, global warming potential (based on a time horizon of 100 years: 100a) is 3.2-5.5 kg $CO_{2.eq}$ per kg of meat (live or carcass weight) and 336-460 kg $CO_{2.eq}$ per market pig. On the other hand, ReCiPe impact per market pig ranges from 60 to 76 Pts, depending on the scenario. Based on all the studied cases, animal feed is responsible for the greatest part of the total impact feed/drinking-water/straw/transportation and transportation is responsible for the second highest impact. A comparison with results from the literature is also provided and critical issues (about feed composition, cleaner-production solutions, etc.) are presented.

Keywords: Life Cycle Assessment (LCA); Pig-meat production; Animal feed; Cumulative Energy Demand (CED); Global Warming Potential (GWP); ReCiPe (midpoint and endpoint approach)

ABBREVIATIONS AND SYMBOLS

CED: Cumulative energy demand

CML01: CML01 method

CML-IA: CML-IA method

$CO_{2.eq}$: CO_2 equivalent

CW: Carcass weight

DALY: Disability adjusted life years

Eco-indicator 99: Eco-indicator 99 method

EDIP97: EDIP97 method

F, W, S, T: Feed, water, straw, transportation

F: Feed

GHG: Greenhouse gas

GWP 100a: Global warming potential with a time horizon of 100 years

GWP 20a: Global warming potential with a time horizon of 20 years

GWP 500a: Global warming potential with a time horizon of 500 years

GWP: Global warming potential

IPCC: Intergovernmental panel on climate change

LCA: Life cycle assessment

LCI: Life cycle inventory

LCIA: Life cycle impact assessment

LW: Live weight

MJ_{prim}: MJ primary

Pts: Points

ReCiPe: ReCiPe method

S: Straw

T: Transportation

W: Water

1. INTRODUCTION

Livestock at commercial level is related with considerable impacts on the environment. This is because animal production (e.g. of pork) is a complex system, involving multiple aspects: production of animal feed, transportation, animal care, breeding, rearing, fattening, waste management, etc. A useful tool for the assessment of the environmental performance of such complex systems is Life Cycle Assessment (LCA). LCA has been applied to pig-production systems and a review reveals that these studies refer to e.g. feed production, entire-system livestock rearing and waste management (McAuliffe et al., 2016). In the following paragraphs, several literature studies about the environmental profile of pig-production systems are presented, revealing crucial factors.

Nguyen et al. (2010) investigated fossil energy and GHG (greenhouse gas) saving potentials of pig farming in Europe. It was noted that in Europe, the highly developed livestock industry is associated with a high burden on resource use and environmental quality. Pig-meat production in North-West Europe (as a base case) was examined (based on different scenarios) in order to examine how improvements (in terms of energy and GHG savings) can be feasibly achieved. The analysis showed that pig farming in Europe presents a high potential to reduce fossil energy use and GHG emissions by improving the following aspects: feed use, manure management/manure utilization.

For the case of France, van der Werf et al. (2005) conducted an LCA study in order to investigate the environmental impact associated with the production and on-farm delivery of concentrated feed for pigs. Feed composition was based on average data for Bretagne (France, year 1998) and on published data for wheat-based, maize-based and co-product based feeds. It was mentioned that the environmental burdens related to production/delivery of pig feed can be decreased by: 1) optimising the fertilisation of the crop-based ingredients, 2) utilising more locally-produced feed ingredients, 3) reducing concentrations of Cu and Zn in the feed and 4) adopting wheat-based rather than maize-based feeds.

Moreover, in the literature there is a review study specifically about European LCA studies on pork production (Reckmann et al., 2012). It was mentioned that these assessments show an average GWP (global warming potential) of 3.6 kg $CO_{2.eq}$ per kg of pork.

Another study (Röös et al., 2013) with emphasis on carbon footprint as an indicator of the environmental impact of meat production (including pork) revealed that: 1) carbon footprint generally acts as an indicator of acidification and eutrophication potential (given the fact that more efficient use of nitrogen leads to less eutrophying and acidifying substances being released to the environment and lower GHG emissions in nitrous oxide form); 2) GHG mitigation strategies based on more efficient use of feed can lead to decreased acidification and eutrophication potential; 3) decreased GHG emissions (because of increased productivity) result in less land requirements for feed production (Röös et al., 2013).

Furthermore, Baumgartner et al. (2008) analysed the environmental impact of grain legume use in animal feed and evaluated the impact of several animal-production systems, including feed production, by means of multiple feeding strategies and different origins of feed. For the analysis, midpoint impact categories were selected (mainly from EDIP97 and CML01 methods). Different European regions/case studies were investigated, including pig-meat production in Catalonia, Spain.

Additional studies are those of: 1) Basset-Mens and van der Werf (2005) about LCA of pig production in France; 2) Eriksson et al. (2005) regarding pig production with emphasis on feed choice (Sweden); 3) Rigolot et al. (2009) about LCA of five virtual pig-production units with different manure-management systems; 4) Sasu-Boakye et al. (2014) regarding livestock protein feed production and the impact on land use and GHG emissions (the study included issues about pig production and emphasis was given on Sweden); 5) González-García et al. (2015) concerning LCA of pig-meat production in Portugal (based on ReCiPe midpoint); 6) Dalgaard et al. (2007) regarding an environmental assessment of Danish pork production; 7) Dourmad et al. (2014) regarding the environmental impact of 15 European pig farming systems in the European Union Q-PorkChains project (conventional and non-conventional systems were evaluated from: Denmark, The Netherlands, Spain, France and Germany); 8) de Miguel et al. (2015) concerning water footprint of the Spanish pork industry; 9) Bava et al. (2015) concerning the environmental impact of the typical heavy pig production in Italy; 10) Noya et al. (2016) regarding carbon and water footprint of pork supply chain in Catalonia, Spain; 11) Espagnol and Demartini (2014) about the environmental impact of extensive outdoor pig-production systems in Corsica, France.

By taking into account:

- The importance of pig-meat production in Spain (Spain is the second country in Europe in swine production), especially in North-East region which is the main pig-production area of Spain (Plà-Aragonés, 2015).

- The fact that most of the literature studies examine CO_2 emissions and there are few studies based on ReCiPe method, the present investigation presents the environmental profile of a pig-production system in North-East of Spain, by means of multiple approaches and LCIA (life cycle impact assessment) methods.

More specifically, the present study includes:

- Evaluation of the eco-profile of pig production based on data of a real pig-farming system, with emphasis on animal feed.
- Presentation of an LCA model based on the newly-developed LCIA method ReCiPe (midpoint and endpoint approach) along with CED (cumulative energy demand) and GWP (PRé, 2014), according to several scenarios (animal feed and drinking-water demand, etc.).
- Estimation of the impact by adopting different functional units.
- Analysis of the impact in terms of each component of animal feed and identification of the ingredients with the maximum impact for each phase of feeding.

The goal of the present work is to:

- Identify critical points related to the proposed pig-farming system (based on multiple approaches, environmental indicators and methods).
- Present results for important environmental issues related with human health, ecosystems and resources.
- Propose solutions for cleaner production.

2. MATERIALS AND METHODS

The implementation of the LCA has been conducted according to ISO 14040 (2006) and ISO 14044 (2006), for the phases of: 1) goal and scope definition, 2) life-cycle inventory, 3) life-cycle impact assessment and 4) interpretation.

2.1. Boundaries and functional units

The whole system includes raising pigs for meat production. More specifically:

- The raising of the animals refers to growing-finishing from an initial body weight of 25 kg to a final body weight of 105 kg.
- The production system has three cycles per year.
- Each cycle includes 120 days and 1872 pigs; thus, there is a production of 5616 pigs per year.
- Taking into account that the weight of one market pig is 105 kg, there is a meat production of 589.68 tonnes live weight (LW) and 465.85 tonnes carcass weight (CW).
- Animal feed is divided into three phases.
- Water consumption (drinking water for the animals), straw usage and transportation (for feed and straw) are included for certain scenarios.

The functional units refer to the production of: 1) 1 market pig, 2) 1 kg of meat LW and 3) 1 kg of meat CW. According to the literature (McAuliffe et al., 2016; Reckmann et al., 2012) the above mentioned functional units can be adopted in the frame of an LCA applied to pig production. In addition, for some cases, the impact is also calculated per kg of animal feed.

2.2. Definition of the studied system

2.2.1. Characteristics

The inputs of the pig-production system are based on data from a real swine farm (intensive pig farming) located in the North-East of Spain. Animal feeding has been separated into three phases: A, B and C (details are presented in section 2.3). The phases A, B and C refer to pigs with a body weight of [25-40), [40-60) and [60-105] kg, respectively.

In terms of growing-pig nutrition, in the work of Noblet (2001) it was noted that the performance of growing pigs is directly associated to energy intake. Under most practical conditions and especially for the case of young growing pigs, *ad libitum* feed intake is insufficient to maximise protein deposition and growth allowed by the potential of the animal. It was also mentioned that the gap between potential growth and actual performance is more crucial in commercial conditions and this gap can be attenuated by feeding high-quality diets (and more especially high-energy diets). Moreover, it was highlighted the importance of the relationship between feed intake, growth, feed efficiency, body composition and energy concentration of the feed.

In the frame of this concept, in the present investigation, taking into account the response of growing pigs to feeding inputs and to parameters such as diet energy concentration and fibre source, the animal nutrition/feed has been separated into three different phases according to the usual practises in the sector. The adoption of different feed compositions for each stage of animal growth is a practice that has been reported in the literature (van der Werf et al., 2005 (France); Reckmann et al., 2013 (Germany); González-García et al., 2015 (Portugal)).

It should be noted that the present pork-production system is representative for Spain. More specifically, it represents large fatteners as part of a production system organised between specialised breeders and fatteners. This organisation is rather common in main pig-producing countries, including Spain. Large fatteners, according to the statistical portrait of the sector in 2014 (Source: Eurostat, 2016), account for more than one third of fattening pigs in ten countries (Belgium, Denmark, Germany, Spain, Italy, Luxembourg, the Netherlands, Finland, Sweden and the United Kingdom) representing three quarters of the EU pork-meat production. Furthermore, the same report states that the number of small fatteners follows a general downward trend in the EU.

2.2.2. Assumptions

Emphasis has been given on feeding input since in pig-meat production systems large environmental burdens are associated with feed production (González-García et al., 2015).

The impact of L-lysine has been calculated based on the inputs of L-lysine which are presented in the work of Marinussen and Kool (2010) (a study about the collection of environmental-impact-assessment data for the amino acids L-lysine, L-threonine (both bio-synthetic produced) and DL-methionine (synthetic produced) used in animal feed). The impact of the other components (wheat, barley, sunflower, etc.) has been taken directly from SimaPro 8.

For the evaluation of the feed impact, the ingredients presenting quantities less than 5 g per kg of feed have not been considered. The ingredients which have been included in the calculations correspond to a total mass of 0.99 kg per kg of feed.

With respect to animal-feed transportation, taking into account that feed has been purchased from the local market (very close to the studied farm) a distance of 20 km has been included. Regarding the transportation of the straw, a small distance of 5 km has been assumed. Certainly, for the calculations, the above mentioned distances have been considered several times (by truck) in order to cover the total annual needs in terms of feed and straw.

2.3. Life cycle inventory (LCI)

SimaPro 8 and Agri-footprint database[1] have been utilized. Agri-footprint is a new LCI database which focuses on food and agricultural sector. The aim of this database is the support of LCA practitioners to perform high quality assessments. Agri-footprint contains a methodologically consistent dataset for a large number of crops, crop products, animal products, animal systems and these inventories can be utilized as secondary data in LCA studies (Durlinger et al., 2014).

In Table 1, details about the materials/inputs considered are presented. Certainly, for an LCA study it is desirable to use secondary data based on country/region specific processes. However, in the frame of the present work, due to the lack of secondary data specifically for Spain, the impact of the basic inputs/ingredients (straw, wheat, barley, sunflower, soybean, maize, sugar beet and fat) has been calculated based on secondary data from Netherlands[2] (Agri-footprint; gross energy allocation). At this point it should be noted that Agri-footprint database has been adopted by other authors for LCA about pig-production systems (Noya et al., 2016: Catalonia, Spain; Bava et al., 2015: Italy).

Concerning the frame of crop cultivation, in the report of Agri-footprint «description of data» it is mentioned that data on crop cultivation is generally based on publically available sources and regarding the feed cultivation model in Agri-Footprint, the following issues are taken into account: crop yield, energy inputs, land use change, water use, artificial fertilizer and lime inputs, animal manure inputs, fertilizer/manure related emissions, emissions from pesticides application (Source: Agri-footprint, Description of data).

[1] For citric acid, sulfuric acid and calcium carbonate, Ecoinvent 3 and ELCD (Source: SimaPro 8) have been utilised.
[2] For the other inputs/ingredients, data for Europe have been used.

Table 1. LCI of the studied system.

INPUT	QUANTITY
Feed for phase A	**kg per kg of feed**
Wheat	0.4700
Barley	0.2265
Sunflower	0.1000
Soybean	0.0775
Maize	0.0500
Beet pulp	0.0200
Fat	0.0232
Calcium carbonate	0.0102
L-lysine	0.0089
Feed for phase B	**kg per kg of feed**
Wheat	0.4700
Barley	0.2898
Sunflower	0.0850
Soybean	0.0538
Maize	0.0500
Fat	0.0178
Calcium carbonate	0.0100
L-lysine	0.0096
Feed for phase C	**kg per kg of feed**
Wheat	0.4701
Barley	0.3330
Sunflower	0.1000
Soybean	0.0393
Fat	0.0245
Calcium carbonate	0.0103
L-lysine	0.0097
Total mass of feed[3]	**Tonnes**
Phase A	178
Phase B	331
Phase C	1026
Additional inputs	
Drinking water consumption	6 *l* per pig per day
Straw usage	0.3 kg per pig per day

[3] The mass of feed per animal per day ranges from 1.3 kg (for body weight 25-30 kg) to 3.1 kg (for body weight 100-105 kg).

2.4. Life cycle impact assessment (LCIA) methods

The developed model has been based on:

1) Cumulative Energy Demand V1.08 / Cumulative energy demand.

2) IPCC 2013 GWP 20a V1.00.

3) IPCC 2013 GWP 100a V1.00.

4) IPCC 2013 GWP 500a V1.00.

5) ReCiPe Midpoint (H) V1.10 / Europe Recipe H: with characterization.

6) ReCiPe Endpoint (H) V1.10 / Europe ReCiPe H/A: single-score.

7) ReCiPe Endpoint (H) V1.10 / Europe ReCiPe H/A: with characterization.

Explanations about the adopted methods are following presented:

Regarding CED, the characterization factors are given for the energy resources divided in 5 impact categories (non-renewable, fossil; non-renewable, nuclear; renewable, biomass; renewable, wind, solar, geothermal; renewable, water) (PRé, 2014).

IPCC 2013 is an update of the method IPCC 2007 (developed by IPCC (Intergovernmental Panel on Climate Change)). This method lists the climate change factors of IPCC based on a timeframe of 20, 100 and 500 years (GWP 20a, GWP 100a and GWP 500a) (PRé, 2014).

ReCiPe is successor of Eco-indicator 99 and CML-IA. The purpose (at the start of the development) was the integration of the problem-oriented approach (CML-IA) and the damage-oriented approach (Eco-indicator 99). The problem-oriented approach includes the impact categories at a midpoint level. ReCiPe has 2 sets of impact categories with associated sets of characterization factors. At the midpoint level, 18 impact categories are addressed: ozone depletion, human toxicity, ionizing radiation, photochemical oxidant formation, particulate matter formation, terrestrial acidification, climate change, terrestrial ecotoxicity, agricultural land occupation, urban land occupation, natural land transformation, marine ecotoxicity, marine eutrophication, fresh water eutrophication, fresh water ecotoxicity, fossil fuel depletion, minerals depletion and fresh water depletion. On the other hand, at the endpoint level most of these midpoint impact categories are multiplied by damage factors and aggregated into 3 endpoint categories: human health, ecosystems and resource surplus costs. The three endpoint categories are normalized, weighted and aggregated into a single-score (PRé, 2014).

The above mentioned methods (which have been adopted in the frame of the present work) show interest for studies about pig-production systems taking into account that:

1) Pig-farming includes processes such as crop and feed production and thereby, emissions to the environment (CO_2, etc.) and consumption of energy and resources.

2) In the literature there are studies about pig-meat production presenting results in terms of energy use and CO_2 emissions (van der Werf et al. (2005): France; Basset-Mens and van der Welf (2005): France; Reckmann et al. (2013): Germany) as well as in terms of ReCiPe impact categories (González-García et al. (2015): Portugal).

With respect to ReCiPe, both midpoint and endpoint categories were adopted since both of these approaches show different advantages and disadvantages. A midpoint-based assessment offers a transparent analysis of environmental impacts with relative low uncertainties. However, midpoint categories are relative difficult to interpret for people which are not experts. On the other hand, the endpoint categories are very easy to understand but the results are less detailed and include higher uncertainties (Ciroth and Franze, 2011).

2.5. Scenarios

The calculation of the impact has been based on different scenarios, by considering: 1) only animal-feed impact (F), 2) the impact of animal feed along with water consumption (drinking water) (F, W), 3) the impact due to feed, drinking-water consumption and straw usage (F, W, S), 4) the impact because of feed, drinking-water consumption, straw usage and transportation (for feed and straw) (F, W, S, T).

Regarding the time horizons, three scenarios have been examined according to GWP 20a, GWP 100a and 500a. In this way, a complete picture of the studied issues in terms of $CO_{2.eq}$ emissions is provided, taking into account that certain substances gradually decompose and become inactive in the long run. It should be noted that GWP over a 100-year period is the most common choice (PRé, 2014).

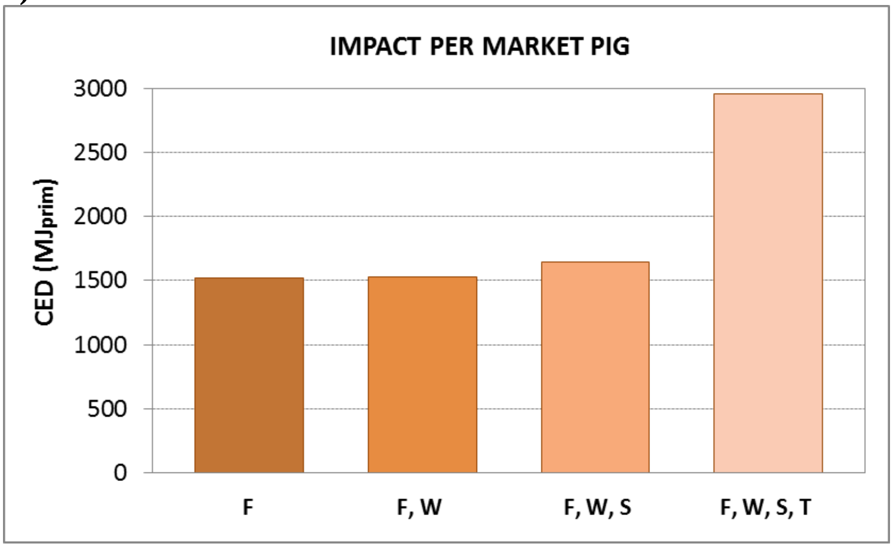
3. RESULTS AND DISCUSSION

3.1. Cumulative energy demand (CED)

In Fig. 1 CED in MJ_{prim} per market pig (Fig. 1a) and in MJ_{prim} per kg LW or CW (Fig. 1b) is presented, based on different scenarios. From Fig. 1(a) it can be seen that CED ranges from 1524 to 2956 MJ_{prim} per market pig and feed shows the maximum percentage (52%) of the total impact (F, W, S, T). In addition, transportation shows the second highest percentage (44% contribution to the total impact F, W, S, T). On the other hand, water and straw present low contributions (less than 4%). The high CED of the feed is associated with factors such as the inputs necessary for crop cultivation and for the feed-production processes. The contribution of each feed component to the total CED impact is analytically presented in section 3.5.

By focusing on the impact per kg of meat, from Fig. 1(b) it can be seen that it varies from 14.5 to 35.6 MJ_{prim} per kg of LW or CW, depending on the scenario. Certainly, the impact based on the CW is higher than the impact based on the LW (there is a difference ranging from around 4 to 7.5 MJ_{prim} per kg of meat).

a)



b)

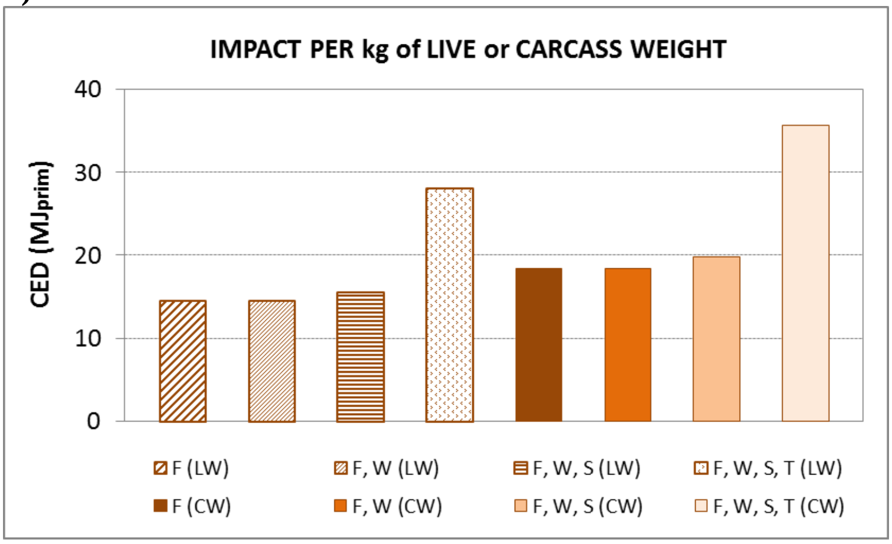


Figure 1. CED impact (in $MJ_{primary}$) per: a) market pig, b) kg live weight (LW) or kg carcass weight (CW). Four scenarios: 1) feed (F), 2) feed and drinking-water (F, W), 3) feed, drinking-water and straw (F, W, S), 4) feed, drinking-water, straw and transportation (F, W, S, T).

3.2. Global warming potential (GWP)

In Fig. 2 GWP in kg $CO_{2.eq}$ per market pig (Fig. 2a) and in kg $CO_{2.eq}$ per kg LW or CW (Fig. 2b) is presented, based on different scenarios.

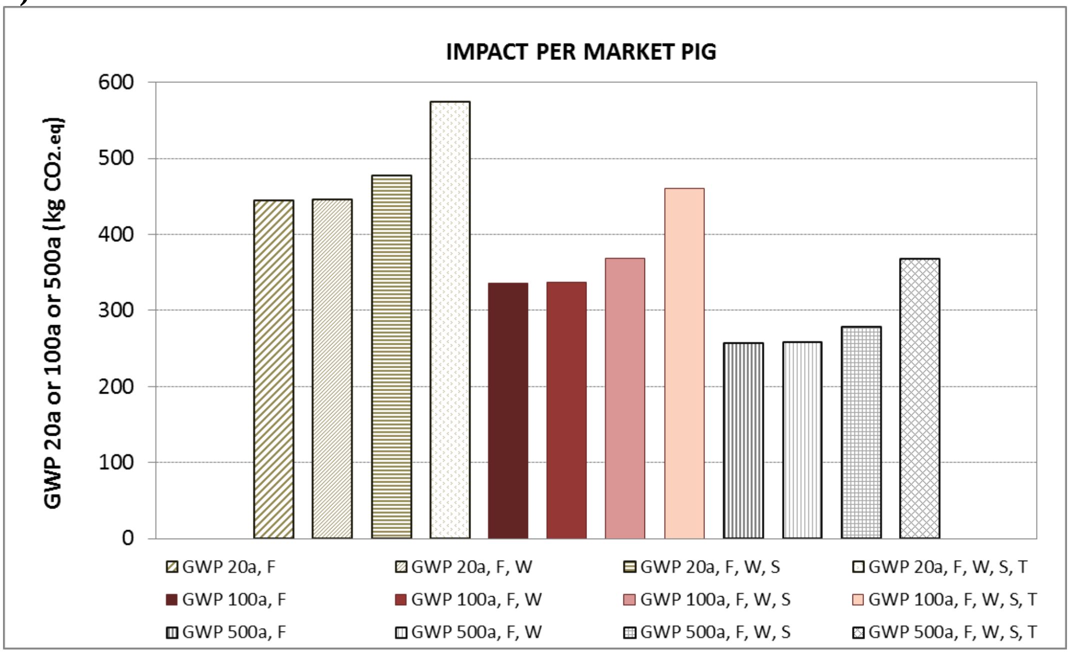
From Fig. 2(a) it can be seen that GWP per market pig (taking into account all the studied cases: three time horizons, etc.) ranges from 257 to 575 kg $CO_{2.eq}$. Feed is responsible for the greatest part of the total (F, W, S, T) GWP (for example for GWP 100a, the feed shows a percentage of 73%). Furthermore, transportation presents the second highest contribution (20% to the total (F, W, S, T) GWP 100a impact) while water and straw show low percentages (less than 7%).

On the other hand, in terms of the time-horizon effect, it can be seen that the impact per market pig (Fig. 2a) shows a difference of 78-207 kg $CO_{2.eq}$, depending on the adopted time horizon.

By examining GWP 100a per kg of meat (Fig. 2b), it can be noticed that the evaluation of the impact per kg of CW results in an impact increase of 0.8-1.2 kg $CO_{2.eq}$ (comparing to the calculations per kg of LW). By taking into consideration all the studied cases of Fig. 2(b), it can be seen that GWP 100a ranges from 3.2 to 5.5 kg $CO_{2.eq}$ per kg of LW or CW.

By comparing CED and GWP 100a results (Figures 1 and 2), it can be observed that feed presents higher contribution to the total impact (F, W, S, T) based on GWP (70-77%) in comparison to the percentage based on CED (52%). The high GWP of the feed is associated with issues such as the utilisation of fertilizers and land-use change because of crop cultivation. Details about the contribution of each feed ingredient to the total GWP 100a are presented in section 3.5.

a)



b)

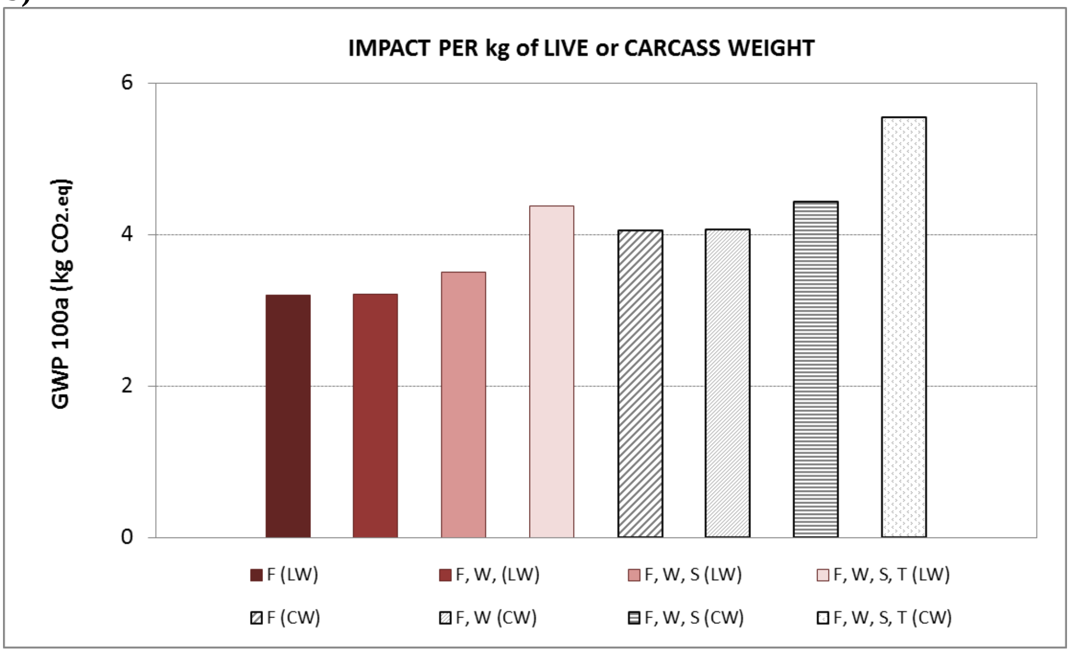


Figure 2. GWP (in kg $CO_{2.eq}$) per: a) market pig (based on GWP 20a, GWP 100a and GWP 500a), b) kg live weight (LW) or kg carcass weight (CW) (based on GWP 100a). Four scenarios: 1) feed (F), 2) feed and drinking-water (F, W), 3) feed, drinking-water and straw (F, W, S), 4) feed, drinking-water, straw and transportation (F, W, S, T).

3.3. ReCiPe midpoint

3.3.1. With characterization

The systems of animal production (pig farms, etc.) include emissions to the environment as well as consumption of resources (water, etc.) related for example with crop/feed production for the animals. The environmental impact of these emissions and the consumption of resources can be illustrated in terms of different midpoint impact categories such as acidification, eutrophication and photochemical oxidant formation potential (González-García et al., 2015). Thereby, for animal-production systems several midpoint impact categories can provide useful information. In the frame of this concept and taking into account that in the literature ReCiPe midpoint approach has been adopted for LCA of pig-meat production (González-García et al., 2015), in the present study results according to ReCiPe midpoint approach are also included.

In Table 2, the impact per market pig, based on ReCiPe midpoint (with characterization), is presented. Table 2 shows that feed is responsible for the greatest part of the total impact (F, W, S, T), showing percentages more than 70% for most of the impact categories (climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, ionising radiation, agricultural land occupation, urban land occupation, natural land transformation and metal depletion). This high impact is related with the inputs e.g. for the cultivation of the crops. On the other hand, water presents low percentages (less than 3.5%) for all the impact categories, except for the category of water depletion (36%). Moreover, the contribution of the straw is less than 23% for all the impact categories. Furthermore, transportation (due to fuel consumption) shows high percentages for certain impact categories: climate change (20%), photochemical oxidant formation (65%), marine ecotoxicity (29%) and fossil depletion (47%).

Table 2. ReCiPe midpoint (with characterization) impact per market pig. Several impact categories (climate change, ozone depletion, etc.). Four scenarios: 1) feed (F), 2) feed and drinking-water (F, W), 3) feed, drinking-water and straw (F, W, S), 4) feed, drinking-water, straw and transportation (F, W, S, T).

CATEGORY	UNITS	F	F, W	F, W, S	F, W, S, T
Climate change	kg CO_2 eq	339.75	341.00	374.72	466.77
Ozone depletion	kg CFC-11 eq	2.70E-06	2.72E-06	2.75E-06	2.94E-06
Terrestrial acidification	kg SO_2 eq	6.99	7.00	8.48	9.15
Freshwater eutrophication	kg P eq	0.08	0.08	0.10	0.10
Marine eutrophication	kg N eq	3.45	3.45	4.41	4.45
Human toxicity	kg 1,4-DB eq	21.09	21.10	28.32	31.80
Photochemical oxidant formation	kg NMVOC	0.58	0.59	0.63	1.80
Particulate matter formation	kg PM10 eq	1.04	1.05	1.25	1.53
Terrestrial ecotoxicity	kg 1,4-DB eq	6.45	6.45	6.57	6.58
Freshwater ecotoxicity	kg 1,4-DB eq	1.27	1.27	1.31	1.32
Marine ecotoxicity	kg 1,4-DB eq	0.17	0.17	0.19	0.26
Ionising radiation	kBq U235 eq	3.36	3.37	3.42	3.65
Agricultural land occupation	m^2a	579.71	579.71	662.53	662.53
Urban land occupation	m^2a	2.22E-03	2.22E-03	2.22E-03	2.22E-03
Natural land transformation	m^2	1.96	1.96	1.96	1.96
Water depletion	m^3	3.82	5.99	5.99	6.00
Metal depletion	kg Fe eq	0.12	0.13	0.13	0.15
Fossil depletion	kg oil eq	30.88	30.99	33.44	63.01

In Table 2, all the midpoint categories of ReCiPe are presented; nevertheless, some of these categories are more important (for pig-production systems) than others. In an LCA study about pig-meat production in Portugal (González-García et al., 2015), by taking into account the impact categories that are the most widely used in environmental studies about animal-production systems, the following impact categories were considered for assessment: climate change, fossil depletion, freshwater eutrophication, marine eutrophication, ozone depletion, photochemical oxidant formation, terrestrial acidification, water depletion and toxicity-related categories (freshwater ecotoxicity, human toxicity, marine ecotoxicity, terrestrial ecotoxicity). By focusing on the above mentioned categories, in the present study (Table 2):

1) Feed and transportation are responsible for the major part of climate change, fossil depletion, photochemical oxidant formation and marine ecotoxicity.

2) Feed and straw show the highest percentages for freshwater eutrophication, marine eutrophication, terrestrial acidification and human toxicity.

3) Feed is responsible for the greatest part of ozone depletion, freshwater ecotoxicity and terrestrial ecotoxicity.

4) Feed and water present the highest percentages for water depletion.

3.4. ReCiPe endpoint

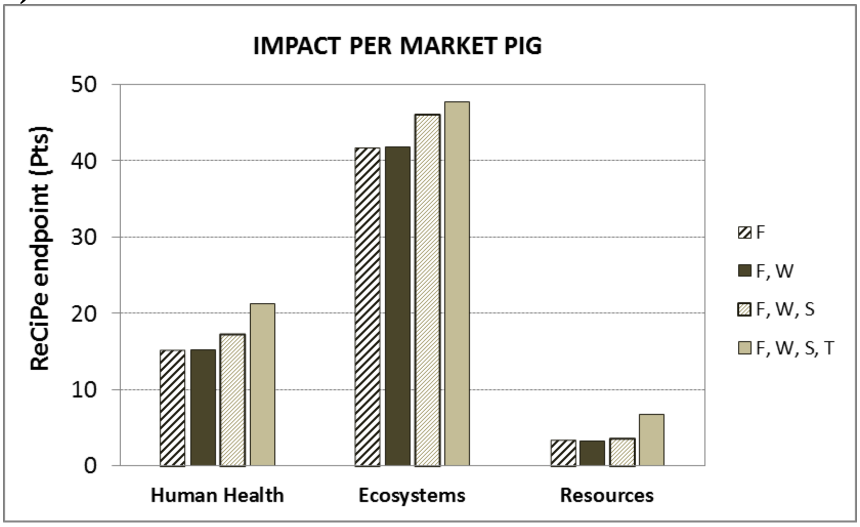
3.4.1. Single-score

In Fig. 3 ReCiPe endpoint impact (single-score for the endpoint categories of human health, ecosystems and resources) per market pig (Fig. 3a), per kg of LW (Fig. 3b) and per kg of CW (Fig. 3c), based on different scenarios, is illustrated.

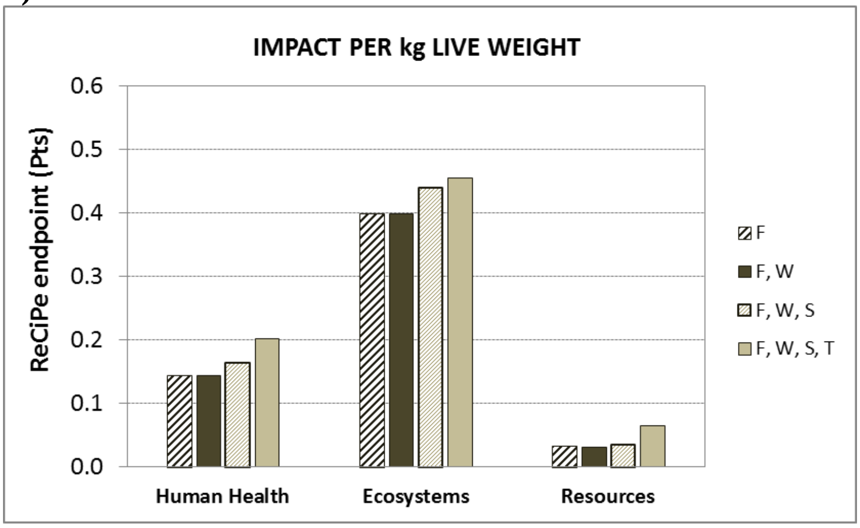
From Fig. 3 it can be observed that among the three endpoint categories, ecosystems show the maximum impact followed by human health. In addition, it is demonstrated that feed is responsible for the greatest part (49-88%) of the total ReCiPe impact, showing the highest percentage (88%) for the category of ecosystems (a fact which is associated e.g. with the inputs necessary for crop cultivation). Moreover, water and straw show contributions less than 10% for all the endpoint categories. On the other hand, the second highest impact (3-47%) is because of transportation, especially for the endpoint category of resources (47%) (certainly, this impact is mainly related with the use of fuel for the truck).

Taking into account all the studied cases of Fig. 3 it can be seen that: 1) the impact per market pig ranges from 3 to 48 Pts (for the category of ecosystems, 42 over 48 Pts are due to feed) and 2) the impact per kg of LW or CW ranges from 0.03 to 0.58 Pts (for the category of ecosystems, 0.50 over 0.58 Pts are due to feed), depending on the endpoint category. Considering the total Pts for all the categories (Fig. 3), the impact per market pig is 60-76 Pts (Fig. 3a) and the impact per kg of LW or CW is about 0.6-0.9 Pts (Fig. 3b and 3c).

a)



b)



c)

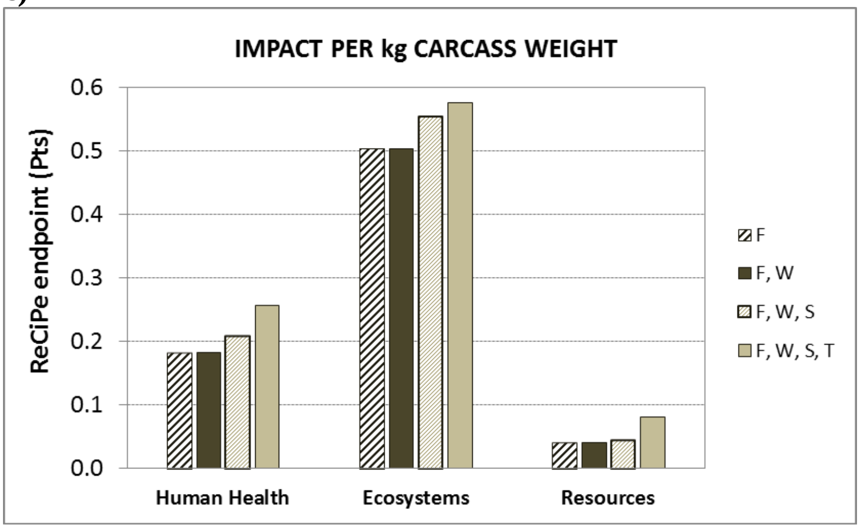


Figure 3. ReCiPe endpoint impact (single-score) in Pts per: a) market pig, b) kg live weight, c) kg carcass weight. Endpoint categories: human health, ecosystems and resources. Four scenarios: 1) feed (F), 2) feed and drinking-water (F, W), 3) feed, drinking-water and straw (F, W, S), 4) feed, drinking-water, straw and transportation (F, W, S, T).

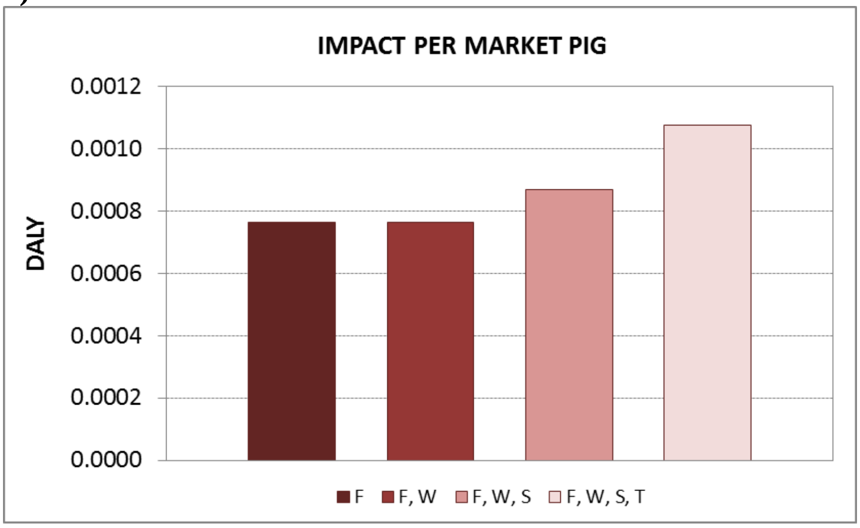
3.4.2. With characterization

In Fig. 4 ReCiPe endpoint impact (with characterization) in DALY (disability adjusted life years) per market pig (Fig. 4a) and per kg of LW or CW (Fig. 4b) is illustrated, based on different scenarios.

By taking into account the impact per market pig (Fig. 4a) it can be observed that there is an impact of 0.00076-0.0011 DALY per market pig. As it is expected, feed shows the highest contribution to the DALY impact (71%), followed by transportation (19%). It should be noted that these DALY values are the sum of the impact categories climate change human health, ozone depletion, human toxicity, photochemical oxidant formation, particulate matter formation and ionising radiation. Among all these categories, climate change human health shows the highest contribution to the total feed DALY (62%) as well as to the total transportation DALY (63%). In addition, the category with the second highest impact is the category of particulate matter formation (with contributions of 36% to the total feed DALY and 36% to the total transportation DALY). Thus, climate change human health and particulate matter formation are the impact categories which are more influenced by the inputs related to feed production and transportation.

On the other hand, by focusing on the impact per kg of meat (Fig. 4b) it can be observed that it varies from 7.3×10^{-6} to 1.3×10^{-5} DALY per kg of LW or CW. Certainly, as it is expected, the values per kg of CW are higher than the values per kg of LW.

a)



b)

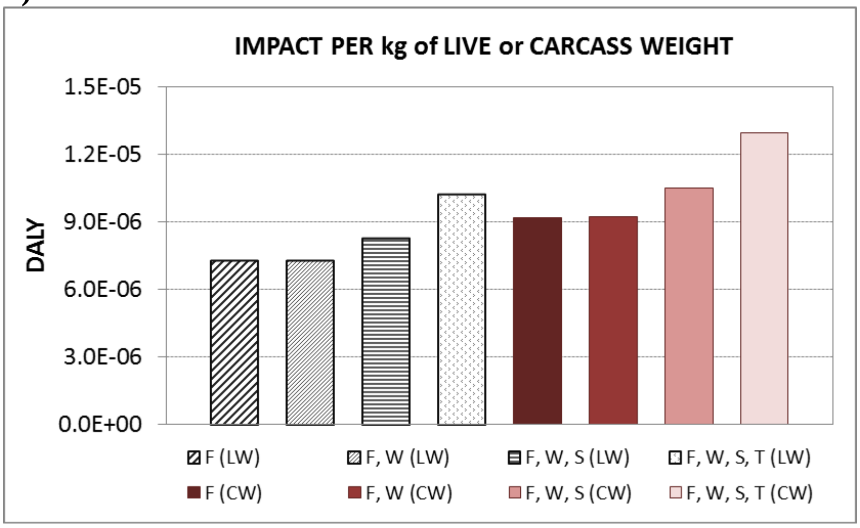


Figure 4. ReCiPe endpoint impact (with characterization) in DALY per: a) market pig, b) kg live weight (LW) or kg carcass weight (CW). Four scenarios: 1) feed (F), 2) feed and drinking-water (F, W), 3) feed, drinking-water and straw (F, W, S), 4) feed, drinking-water, straw and transportation (F, W, S, T).

3.5. The impact of each feed component

In the present section, emphasis is given on the impact due to animal feed. In Fig. 5 the total feed impact (for phases A, B and C), based on CED, GWP 100a and ReCiPe endpoint (single-score) is illustrated. From Fig. 5 it can be observed that: 1) from phase A to phase B there is an increase of 609 GJ_{prim}, 122 t $CO_{2.eq}$ and 24 mPts, 2) from phase B to phase C there is an increase of 4163 GJ_{prim}, 915 t $CO_{2.eq}$ and 162 mPts. Thus, the difference between phase B and C is considerably more pronounced than the difference between phase A and B. More analytically, based on CED, GWP 100a and ReCiPe, phase C is responsible for 68% of the total impact. This considerable difference is related with the rapid change in animal requirements (in terms of nutrients, energy, proteins, etc.) from phase B (body weight 40-60 kg) to phase C (body weight 60-105 kg). These accelerated requirements are also associated with a remarkable increase in the quantity of feed necessary for phase C. More analytically, regarding the feed quantities, from Table 1 it can be seen that from phase A to B there is an increase of 153 tonnes while from phase B to C there is an increase of 695 tonnes.

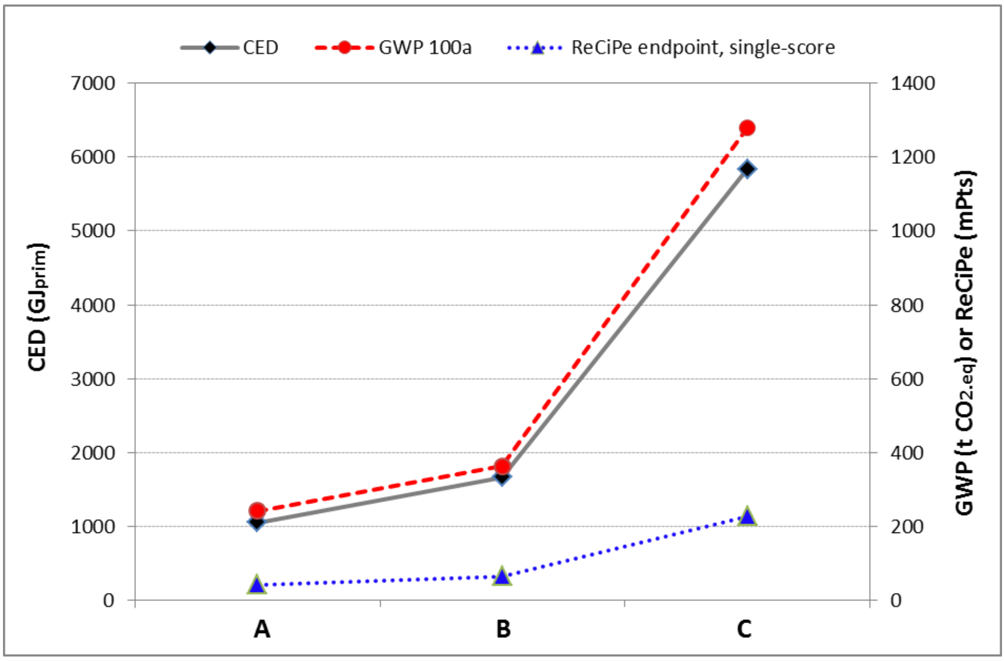


Figure 5. The total impact due to animal feed for phases A, B and C (xx´ axis) according to: CED (GJ_{prim}) (yy´ axis left), GWP 100a (t $CO_{2.eq}$) (yy´ axis right) and ReCiPe endpoint single-score (mPts) (yy´ axis right).

Regarding the contribution of each feed ingredient to the total feed CED, from Fig. 6 it can be observed that for all the phases (phase A: Fig. 6a; phase B: Fig. 6b; phase C: Fig. 6c) the maximum CED impact (39-47%) is attributed to the component «fat». On the other hand, wheat, barley and sunflower contribute 8-20% to the total CED impact.

With respect to GWP, in Fig. 7 GWP 100a of each feed ingredient is illustrated. Taking into account the results for all the phases (phase A: Fig. 7a; phase B: Fig. 7b; phase C: Fig. 7c), it can be noted that «fat» is responsible for the major part of the total GWP 100a (48-58%), followed by wheat and soybean (with percentages 11-22%).

In addition, in Fig. 8 ReCiPe endpoint (single-score) results are illustrated and it can be observed that for all the phases (phase A: Fig. 8a; phase B: Fig. 8b; phase C: Fig. 8c) «fat» shows the maximum impact (36-45% of the total impact). On the other hand, wheat, barley, sunflower and soybean show percentages ranging from 7% to 22%.

By taking into account all the results presented in Figures 6-8, it can be seen that:

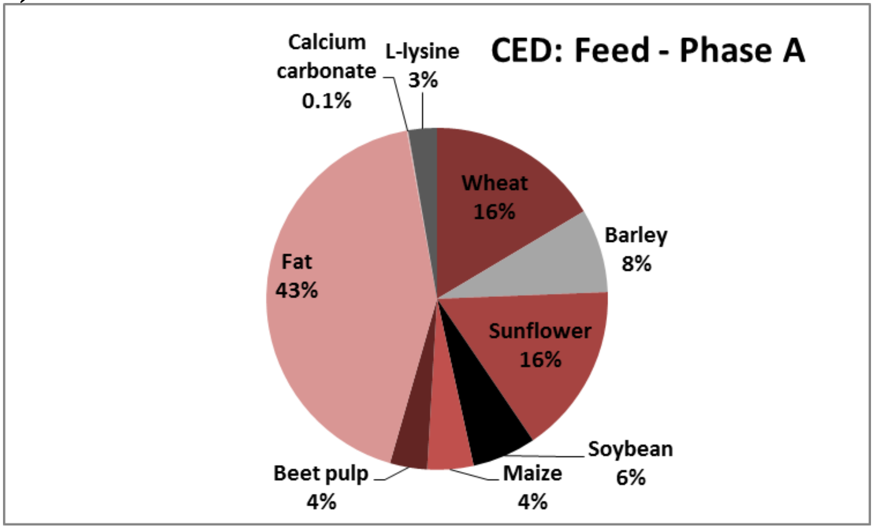
- There are differences between the findings based on CED, GWP100a, ReCiPe and these differences are more evident for the ingredient «fat», for sunflower and for soybean.
- The ingredient «fat» presents its highest contribution (58%) for the case of phase C according to GWP 100a (Fig. 7c).
- Soybean has percentages 3-6% based on CED, 12-22% based on GWP 100a, 12-22% based on ReCiPe and it presents its highest contribution (22%) for phase A according to GWP 100a and ReCiPe (Figures 7a and 8a).
- Sunflower has percentages 16-17% based on CED, 8-9% based on GWP 100a and 15-17% based on ReCiPe; thus, for CED and ReCiPe sunflower presents almost double percentages than for GWP 100a.
- The impact for wheat and barley also shows differences between CED, GWP 100a and ReCiPe but these differences are not so marked as for the component «fat», for sunflower and for soybean.

With respect to the calculation of the impact of the ingredient «fat», «fat from animals» (Agri-footprint database) has been considered. The «fat from animals» is an animal feed containing co-products from animals (dry rendering). The percentage of «fat» component to 1 kg of feed is 2% for all the feeding phases, remarkably lower than the percentages of the other components (Table 1). However, taking into account the high impact for the production of this ingredient, «fat» shows the highest contribution to the total impact of the feed. Thus, even if other components such as wheat and barley present quite high percentages (23-47% on a basis of 1 kg of feed) in the feed composition (Table 1), their contribution to the total impact is considerably lower in comparison to the ingredient «fat».

Specifically for rendering (which is included for the production of «fat from animals») it should be mentioned that it is an essential part of the meat processing industry. Rendering converts meat by-products into useful commodities such as meat meal and feed for animals. The basic aims of rendering are: sterilisation (in order to make the products safe); recovery of fat (to make the meal suitable for milling and stabilize it against oxidation); drying (in order to prevent bacterial growth and to facilitate transportation/storage). Rendering is carried out by adopting a number of different systems and processes, including heating of the material to high temperatures. In general, the energy consumption for rendering is very high, especially for the drying step (Source: Cleaner Production Assessment in Meat Processing).

It should be also noted that the above mentioned differences in terms of the contribution of each component to the total feed impact (Figures 6-8) are related with factors such as the inputs considered for the cultivation of the different crops, transportation (for some cases transportation may include truck, sea ship, etc. and may remarkably influence the total impact) and the processes utilized for the production of each feed component. Thus, it should be highlighted that the present findings are based on certain sources of data and may differ according to factors such as crop yields, agricultural practices, industrial processes and transportation considered for the calculation of the impact of each feed ingredient. Taking into account that for some cases certain of the above mentioned issues can be country/region specific, uncertainty may arise.

a)



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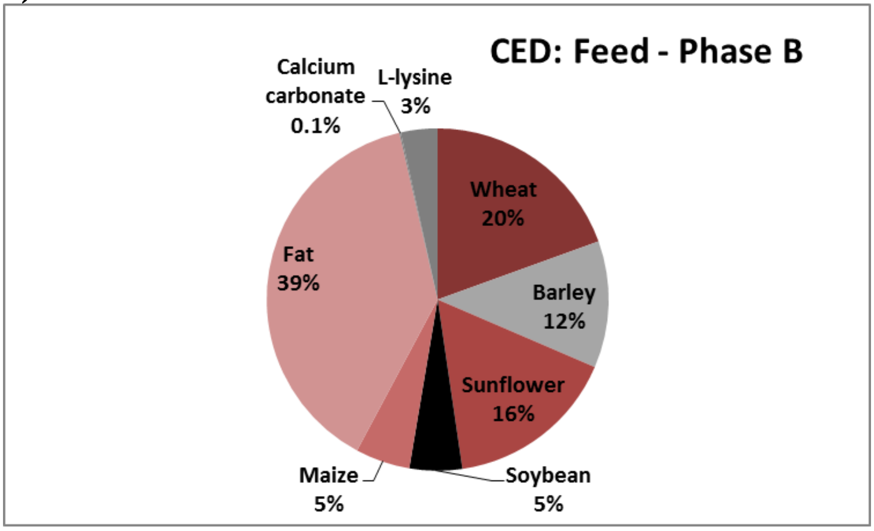

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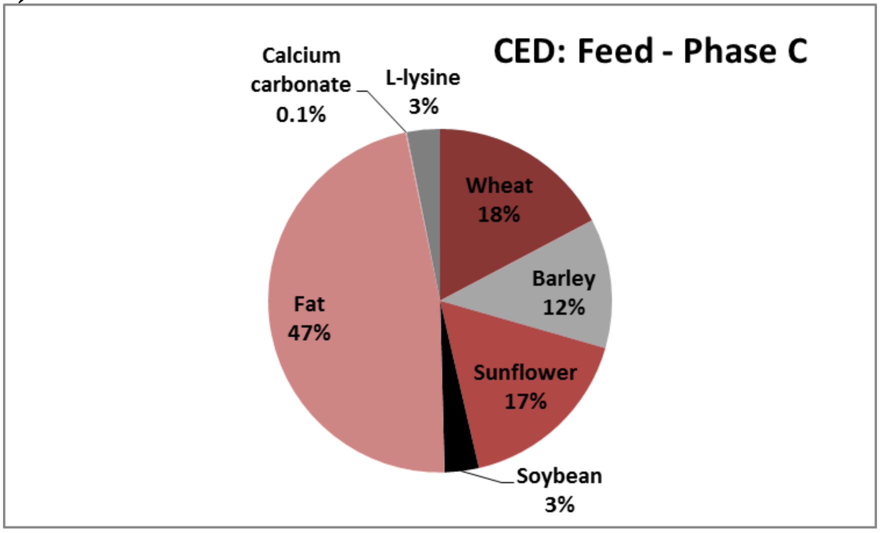


Figure 6. The contribution of each feed component to the total impact of animal feed, based on CED, for the feeding phases: a) A, b) B and c) C.

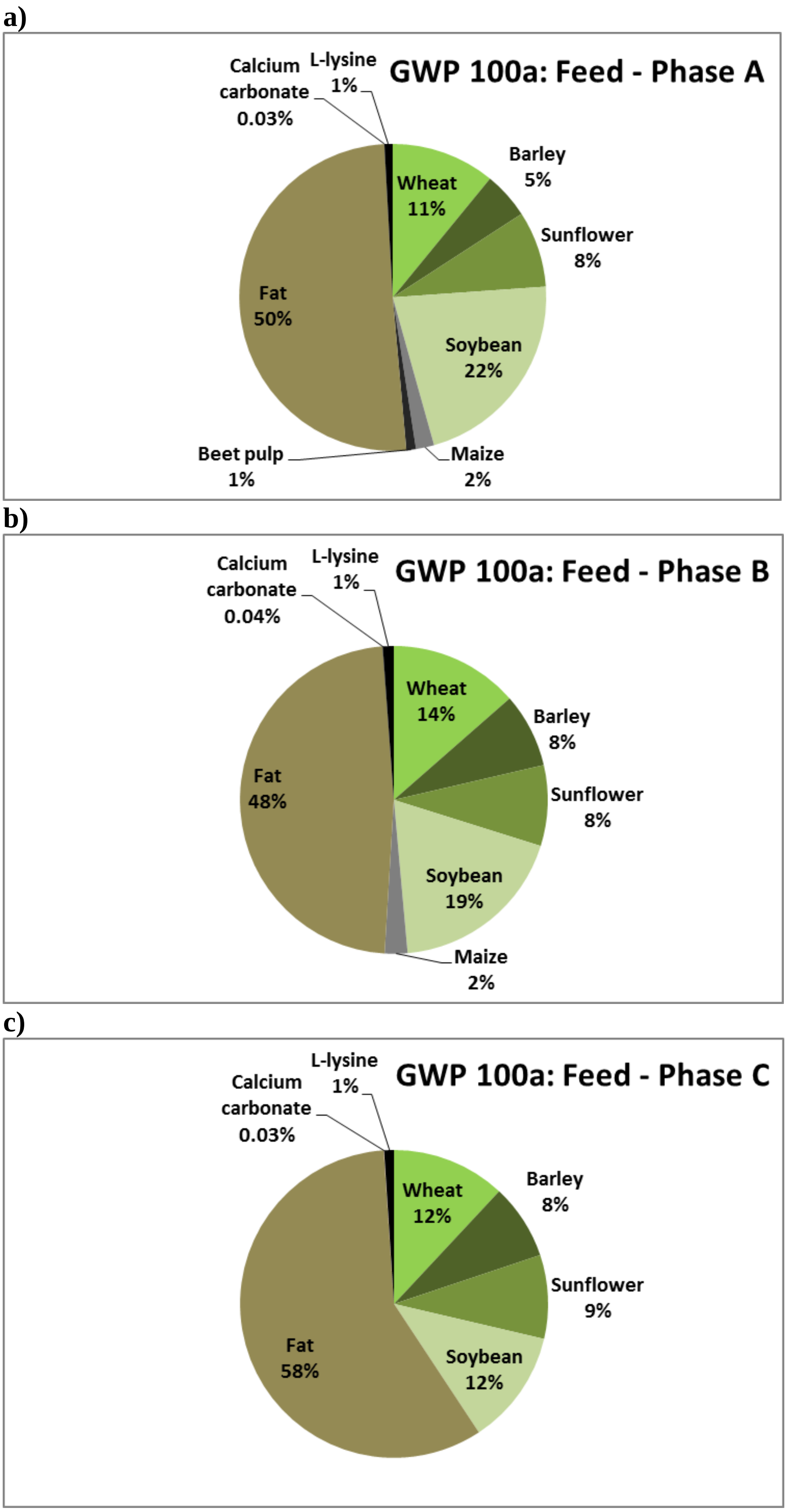
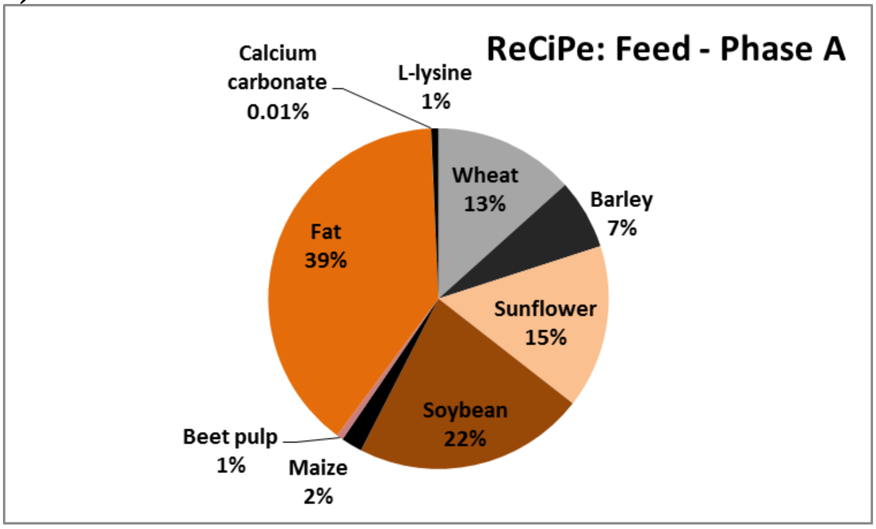


Figure 7. The contribution of each feed component to the total impact of animal feed, based on GWP100a, for the feeding phases: a) A, b) B and c) C.

a)



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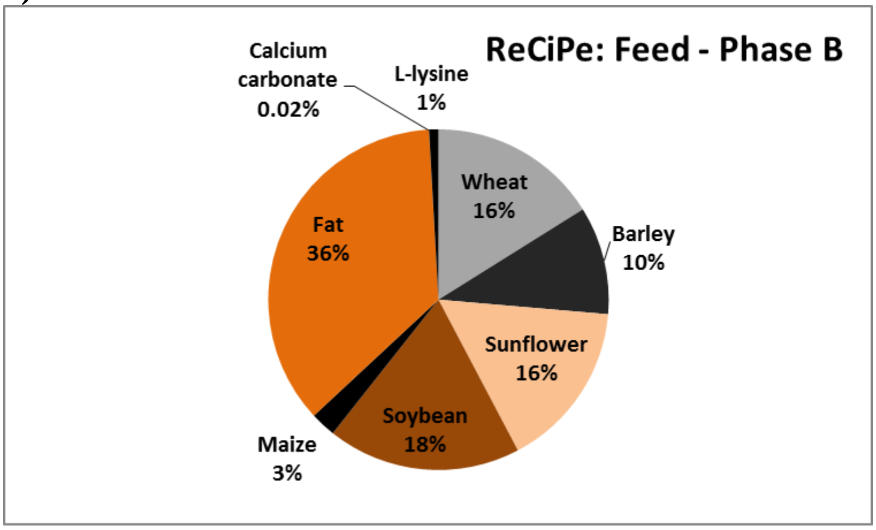

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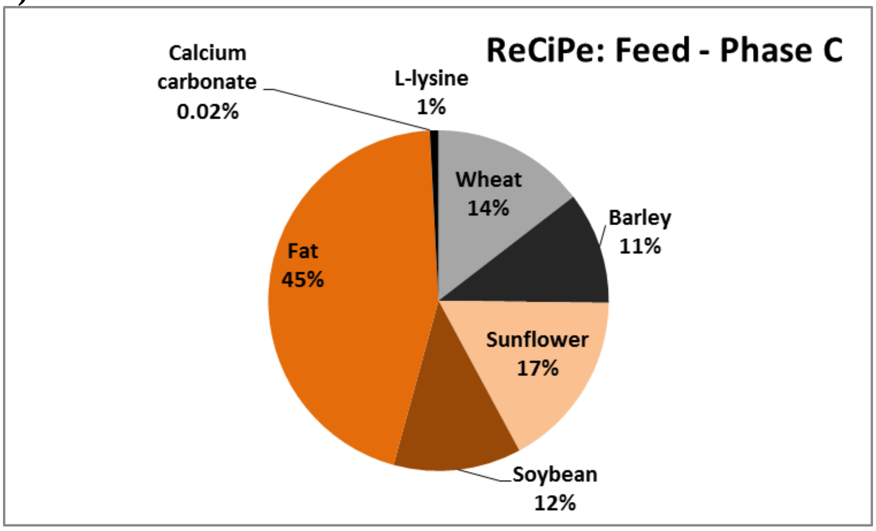

Figure 8. The contribution of each feed component to the total impact of animal feed, based on ReCiPe endpoint (single-score), for the feeding phases: a) A, b) B and c) C.

3.6. Findings from the literature and findings from the present study

In Table 3, results from the present work along with results from the literature (based on energy use, $CO_{2.eq}$ emissions and ReCiPe midpoint for several pig-production systems in Europe) are presented. Even if a direct comparison is not possible, from Table 3 it can be seen that, in general, there is quite good accordance between the findings of the present work and those of the literature. A direct comparison is not possible for several reasons. First of all, pig production differs from country to country. For example, in Spain pig production is very specialized, with vertical integration of producers around companies (Plà-Aragonés, 2015). Furthermore, other reasons are related to differences in terms of the LCA study (boundaries of the systems, assumptions, stages of the life-cycle that are taken into account, etc.).

Table 3. Results from the present study and results from the literature.

STUDY/COUNTRY	RESULTS
	Energy use
Present study/Spain	5.6 MJ_{prim} per kg of animal feed 14.5-35.6 MJ_{prim} per kg of LW or CW, depending on the scenario
Baumgartner et al. (2008)/Spain	31.6 MJ-eq per kg of pork LW (feed based on European grain legumes) 33.6 MJ-eq per kg of pork LW (feed based on soya bean meal from overseas)
van der Werf et al. (2005)/France	Production and delivery of 1 kg of feed (finishing pigs): energy use 3.3-6.1 MJ
Basset-Mens and van der Welf (2005)/France	Non-renewable energy (MJ LHV): 15.9-22.2 MJ per kg of pig
Reckmann et al. (2013)/Germany	Non-renewable energy use: 18 MJ for feed production (impact per kg of pork)
	$CO_{2.eq}$ emissions
Present study/Spain	3.2-5.5 kg $CO_{2.eq}$ per kg of LW or CW (GWP 100a) 336-460 kg $CO_{2.eq}$ per market pig, depending on the scenario (GWP 100a) 1.2 kg $CO_{2.eq}$ per kg of feed (GWP 100a)
Baumgartner et al. (2008)/Spain	3.78 kg $CO_{2.eq}$ per kg of pork LW (feed based on European grain legumes) 3.85 kg $CO_{2.eq}$ per kg of pork LW (feed based on soya bean meal from overseas), GWP 100a
Basset-Mens and van der Welf (2005)/France	2.30-3.97 kg $CO_{2.eq}$ per kg of pig
van der Werf et al. (2005)/France	Production and delivery of 1 kg of feed (finishing pigs): 0.472-0.792 kg $CO_{2.eq}$
Reckmann et al. (2013)/Germany	3.22 kg $CO_{2.eq}$ per kg of pork (for total pork production)
Reckmann et al. (2012)/Europe (review study)	Average GWP: 3.6 kg $CO_{2.eq}$ per kg of pork
	ReCiPe midpoint (with characterization)
Present study/Spain	0.017 kg NMVOC/kg LW; 0.022 kg NMVOC/kg CW Photochemical oxidant formation (including F, W, S, T) 0.042 kg N eq/kg LW; 0.054 kg N eq/kg CW Marine eutrophication (including F, W, S, T) 0.600 kg oil eq/kg LW; 0.760 kg oil eq/kg CW Fossil depletion (including F, W, S, T)
González-García et al. (2015)/Portugal	0.01491 kg NMVOC/kg CW: Photochemical oxidant formation 0.03219 kg N eq/kg LW; 0.04127 kg N eq/kg CW: Marine eutrophication 0.457 kg oil eq/kg CW: Fossil depletion

3.7. Uncertainty, future prospects and identification of ways to reduce the impact of the proposed system

The conclusions drawn from the present work are based on certain assumptions. By taking into account the fact that the results of an LCA can be influenced by several sources of uncertainty such as feed composition and water footprint (for the case of LCA about pork industry) (de Miguel et al., 2015), a future prospect of the present study could be a sensitivity analysis for crucial parameters which considerably affect the ecological profile of the proposed pig-production system.

For example, scenarios, based on difference sources of data, e.g. for the feed ingredient «fat» (since it shows the highest impact among all the feed components), could provide useful information.

In addition, another future prospect could be the inclusion in the study issues related to the health of the animals and the utilization of medical supplements (e.g. antibiotics) as well as scenarios about manure management.

With respect to the uncertainty related to the sources of data, crop yields, agricultural practices and country/region specific processes, a discussion has been presented in section 3.5. It should be noted that another source of uncertainly can be related with the toxicity models of the adopted LCIA methods.

Moreover, Espagnol and Demartini (2014) in their work about the environmental impact of extensive outdoor pig-production in Corsica, France, noted that: 1) the extensive outdoor pig-production systems in Corsica are quite different from the conventional production systems of Europe, 2) the animals are partially fed by natural feeds such as acorns and chestnuts, 3) due to the longer lifetime of the pigs and their lower technical performance, the environmental impact of a kilogram of pig until it leaves the farm gate is expected to be higher, 4) the increase in the impact compared to conventional production systems could be compensated by the utilization of natural feed in the diet of the pigs. It was also mentioned that the sensitivity of the results to the diet of these systems is relevant, highlighting the importance of natural feed because it modifies the inventory data (amount of feed, etc.). In the frame of this concept, Halberg et al. (2010) concluded that even if the free-range system theoretically has agro-ecological advantages over the indoor-fattening system and the tent system because of a larger grass-clover area, this potential is difficult to be implemented in practice (e.g. due to problems of leaching on sandy soil). Only if forage contributed to a larger proportion to the pig-feed uptake the free-range system could be economically and environmentally competitive (Halberg et al., 2010) as for the case of Iberian pig-production systems (Trienekens and Wognum, 2013). In addition, the improvement of nitrogen cycling and efficiency is a crucial factor for the reduction of the overall environmental impact of the organic pig meat (Halberg et al., 2010). The importance of the reduction of the nitrogen and phosphorous excretions has been highlighted in the work of Dubeau et al. (2011) (a study about formulating diets for growing pigs based on environmental and economic considerations).

Taking into account the findings of the present work as well as critical issues about pig-meat production which are highlighted in the literature, several ways to reduce the impact of the proposed system are following presented:

- Replacement of the «fat» ingredient with other feed components which have equal effect on animal growth but less impact on the environment.
- Diets formulated with higher levels of crops which require low inputs and show low environmental impact during their cultivation.
- Adoption of eco-friendly/sustainable agricultural practices (preserving of biodiversity, reduction of GHG emissions, protection of the soil, conservation of the water, restrictions in terms of the use of artificial chemical fertilizers and pesticides, etc.) for

the cultivation of the crops which are utilized as feed components. For example, eutrophication is higher when synthetic fertilizers are utilized.

- Production (a part or all) of the feed components on farm and/or use of locally produced feed components. In this way, the environmental impact due to e.g. overseas transportation can be considerably reduced.

- Manure management/manure utilization (e.g. for fertilizers and for energy production by means of biogas generation).

- Adoption of efficient strategies which can reduce the cost of pig-meat production (Plà-Aragonés, 2015) since for some cases cost reduction means use of less material inputs and reduction of the environmental impact.

4. CONCLUSIONS

The present work based on CED, IPCC GWP, ReCiPe and different functional units presents an environmental assessment of an intensive pork-production system in North-East of Spain. The raising of the animals refers to growing-finishing: from an initial body weight of 25 kg to a final body weight of 105 kg. The system has three cycles per year (each cycle includes 120 days and 1872 pigs). Emphasis is given on animal feeding while the impact of drinking-water consumption, straw usage and transportation (for feed and straw) are also taken into account for certain scenarios. The investigation is based on data from a real farming system and animal feeding is separated into three different phases (A, B and C for animal body weight of 25-40, 40-60 and 60-105 kg, respectively). The results demonstrate that:

1) There is a CED impact of 5.6 MJ_{prim} per kg of animal feed and 14.5-35.6 MJ_{prim} per kg of LW or CW.

2) GWP 100a is 3.2-5.5 kg $CO_{2.eq}$ per kg of LW or CW and 336-460 kg $CO_{2.eq}$ per market pig.

3) The ReCiPe impact ranges from 60 to 76 Pts per market pig.

4) Based on all the studied cases, animal feed (especially the component «fat») is responsible for the greatest part of the total impact feed/drinking-water/straw/transportation while transportation accounts for the second highest impact.

Issues about uncertainty (related with the adopted sources of data, etc.) and identification of ways to reduce the impact of the proposed system (replacement of «fat» ingredient with other feed components which have equal effect on animal growth but less environmental impact; adoption of diets formulated with higher levels of crops which show low environmental impact; utilization of eco-friendly and sustainable agricultural practices, etc.) are also included and critically discussed.

Finally, results of the present work are presented along with literature data. In general, there is quite good agreement between the present findings and those of the literature, taking into account that a direct comparison is not possible. This is because there are differences between the present investigation and those of the literature studies (for example in terms of system boundaries).

Conclusively, given the importance of pig production in Spain, the present work offers useful information about the ecological profile of a real pork-production system, representative for Spain, based on multiple methods and environmental indicators, highlighting important issues for cleaner production.

ACKNOWLEDGEMENTS

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